

BIOMARKERS IN THERMAL SPRING CARBONATES: IMPLICATIONS FOR MARS. Carlton C. Allen¹ and David S. McKay², ¹Lockheed Martin, Houston, TX 77258 carlton.c.allen1@jsc.nasa.gov ²NASA Johnson Space Center, Houston, TX 77058.

Evidence of possible relict biogenic activity has been reported in carbonate inclusions within martian meteorite ALH84001 [1]. The initial evidence included ovoid and elongated forms 50-500 nm in length, morphologically similar to but significantly smaller than many terrestrial microbes. More recently, thin structures resembling the remains of organic biofilms have been reported in the same meteorite [2].

Carbonates have also been discussed in the context of Mars sample return missions. Thermal spring deposits have often been cited as prime locations for exobiological exploration [3]. By analogy to Earth, specialized microbes may have existed in the heated, mineralized waters, and precipitates of carbonate and/or silica from these waters may have trapped and preserved evidence of life. Since the geological interactions which produce thermal springs can be recognized in orbital imagery, directed searches for microfossils in such deposits are deemed possible [4].

We are engaged in a study of the signatures produced by contemporary biogenic activity (biomarkers) in carbonate-precipitating thermal springs [5,6]. We are examining the microbes which live in such environments and the preservation of microbial forms, biofilms and petrographic fabrics indicative of life in thermal spring mineral deposits.

This work is part of a much more extensive study to refine the appropriate tools, techniques and approaches to seek evidence of life in a range of planetary samples. A deeper understanding of biological signatures will prepare us for the detailed search for life on Mars and eventually on other planets. Overall, the study of biomarkers in rocks and soils will provide insight into the evolution of life because such signatures are a record of how life interacts with its environment, how it adapts to changing conditions and how life can influence geology and climate. It is possible that subtle biological signatures left in rocks and soils may be the only evidence for life on Mars. We need to understand these signatures and their message. Otherwise we will not be able to separate true biomarkers from non-biologic features which may mimic their signatures. It is clear that we must have a better understanding of this problem by the time Mars samples are returned to Earth.

Biomarkers in thermal spring carbonates. We are currently studying samples from three active thermal springs: Le Zitelle in the Viterbo region of Italy [7],

Narrow Gauge in the Mammoth complex of Yellowstone National Park, Wyoming [8] and Hot Springs National Park, Arkansas [9]. In each case, water reaches the surface at 60 to 70°C and near-neutral pH (6.3 to 7.5), rapidly precipitating large amounts of the minerals aragonite and calcite.

We concentrated on samples from the hottest areas of each spring. The Italian and Yellowstone springs were sampled at the surface, while the Arkansas springs were sampled below ground. Various samples were fixed in glutaraldehyde, air dried or critical point dried, etched in 1% HCl and examined in a high resolution SEM (details in 5,6).

Microbes The near-vent environments of thermal springs support a variety of microorganisms. *Thermothrix thiopara*, a prolific sulfur-oxidizing bacterium [10], is the highest-temperature species identified at our site in Yellowstone. Pentecost [11] identified a species of the photosynthetic, filamentous bacteria *Chloroflexus* as the dominant form immediately downstream from the vent of the Italian spring. Spherical microbes as large as 15 µm in diameter populate the waters at Hot Springs. Rod-shaped microbes several micrometers in length are found in samples from all three sites [5,6].

The thermal spring deposits also contain forms, many of which appear to be biological, significantly smaller than conventional bacteria. Large numbers of 100-200 nm spheres, the “nanobacteria” described by Folk [12], are common in portions of the Italian and Yellowstone carbonates. The spheres are composed of C, O, F, P and Ca with detectable Si and S, and are often found enmeshed in organic mucus [6]. Numerous 300-500 nm rods and spheres, some apparently dividing, populate the Arkansas samples.

Many of the microbes die and their remains are rapidly destroyed by the process of carbonate precipitation. SEM examination of aragonite masses precipitated on *Thermothrix* filaments revealed the dissolved remains of microbes but no intact cells [6]. Organic matter is generally rare in carbonate sinters deposited at >30°C, suggesting that decomposition rates in such thermal environments are very high [13].

While thermal spring microbes are apparently poorly preserved in carbonates, fossilization by silica can provide enduring evidence of life. Thermophilic bacteria are well preserved in silica sinter deposited by

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many Yellowstone thermal features [14]. Similar fossil assemblages have been described in siliceous thermal spring deposits as old as 400 Ma [15].

Biofilms The three-dimensional network of polysaccharide mucus, living cells and cell remains which constitutes a biofilm is a distinctive macroscopic biomarker. Carbonate samples from all three of our sites contain biofilms. These films are most abundant in the Yellowstone samples [6].

Biofilms are stable in water as hot as 70°C and retain their three dimensional nature as the water cools. Upon drying, however, the mucus shrinks and deforms but preserves its intercellular binding structure. Carbonate samples still display extensive biofilm remains after years of desiccation [6].

Morphologic evidence of biofilms can be preserved by mineralization. Cady and Farmer [14] have demonstrated that silica in thermal springs preferentially nucleates on and preserves organic mucus. Westall [16] provides evidence of silicified biofilm in deep-sea sediments at least 5.5 Ma in age. Sumner [17] describes 3-20 μm thick calcite laminae, interpreted as the fossilized remains of microbial mats, in 2.5 Ga old rocks.

Petrographic fabrics The importance of microbes in promoting the deposition of calcium carbonate, particularly aragonite, in thermal springs is a matter of ongoing debate. Pentecost [11] argues against significant microbial influence in the case of Yellowstone deposits. He accepts microbially-induced precipitation only in cases where aragonite crystals clearly copied the structures of filamentary bacteria. Other investigators, however, provide evidence for a range of bacterially induced lithification styles [18].

Thermothrix thiopara, found near the vents of our Yellowstone sampling sites, forms filaments up to 10 cm long. Immediately downstream the filaments become overgrown by aragonite. The result is a mass of parallel aragonite needles, each millimeters in diameter and centimeters long, which closely mimics the *Thermothrix* filaments. In this case bacterially-induced precipitation yields a distinctive petrographic fabric in the carbonate rocks which is specifically attributable to life. This fabric has been recognized in deposits as old as ~360 Ma [13].

Implications for Mars. Extensive previous studies of life in carbonate thermal springs, coupled with our own results, have implications in the search for evidence of martian life:

- Specialized microbes can exist in carbonate-precipitating environments as hot as 70°C.
- Several types of microorganisms in such environments have dimensions significantly <1 μm .
- Biofilms are characteristic of thermal spring microbial communities.
- Microbes are poorly preserved in thermal spring carbonates.
- Silicified microbes and biofilms can be well preserved over geologic time.
- Some petrographic fabrics, recognizable in the geologic record, are specifically attributable to thermal springs microorganisms.

These observations support the interpretation of submicrometer features in ALH84001 as possible relict life forms and biofilms. They also support the sample return strategy of searching for a variety of biomarkers in thermal spring deposits on Mars.

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